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**Low-Vulnerability Explosives (LOVEX) for Mass-Use Warheads
Part I:
The Processing and Vulnerability Testing of LOVEX Formulations
RX-35-AQ, RX-35-AS, and RX-35-AT**

**Cesar Pruneda, Edward Jessop, Raymond McGuire,
Connie Walkup, Wardell Black, and Frank Helm**

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Abstract

Previous low-vulnerability explosives (LOVEX) formulations were optimized to some extent with respect to performance, cost, and decreased vulnerability in 4-in.-diameter hardware. However, these same formulations were not optimized with respect to, among other things, the binder cure chemistry, sympathetic detonation, and thermal stability (cook-off) in 8-in.-diameter hardware. This report focuses on modification of the polymer binder and the formulation composition to improve both the quality of the cured explosive and the insensitivity of LOVEX formulations to sympathetic detonation in 8-in.-diameter hardware. The thermal-stability issue is the focus of ongoing work and will be addressed in future reports.

We discuss the results of our efforts to improve both the binder chemistry and the insensitivity of LOVEX formulations to sympathetic detonation. In particular, we discuss the modified polymer system used and the 8-in.-diameter sympathetic-detonation test results of three LOVEX formulations: RX-35-AQ, RX-35-AS, and RX-35-AT. LOVEX formulations have been developed that do not sympathetically detonate in 8-in.-diameter hardware and that have very good low-viscosity processing properties.

Introduction

We have an ongoing effort to develop low-vulnerability explosives for use in mass-use or general-purpose bombs. The intention is to develop explosives with lower vulnerability to battle environments (sympathetic detonation, bullets, fragments, cook-off) than current explosives (TNT, H-6, Comp-B) without sacrificing performance or increasing costs. We have previously reported on the results of our initial developmental efforts on LOVEX.¹ In this report, we discuss changes in the original polymer binder and formulation compositions. These were changed to improve both large-scale (>10 kg) process reproducibility and sympathetic-detonation response in 8-in.-diameter hardware.

Previous LOVEX formulations used polyethylene glycol (PEG)* with an isocyanate (Desmodur N-100)[†] catalyzed with dibutyl tin dilaurate[‡] as the binder system. This binder system resulted in formulations with variable cures (Shore hardness 7 to 30) at large-scale mixes (>10 kg) when a hardness of Shore 40 to 50 was expected. A trifunctional poly(e-caprolactone) was added to the difunctional PEG to increase the cross-link density of the cured polymer while maintaining a long pot-life. This, and a modified ingredient-addition sequence, resulted in a decrease in the formulation binder variability.

To maintain high performance, previous LOVEX formulations contained relatively large amounts of nitramine (RDX) and an energetic liquid plasticizer (nitroglycerin/triacetin). Examples of some of these LOVEX formulations are shown in Table 1. All the LOVEX formulations in Table 1 were insensitive to sympathetic detonation in 4-in.-diameter hardware. However, in 8-in.-diameter hardware, RX-35-AN sympathetically detonated (see Fig. 1 for a typical experimental setup). This sensitivity was attributed to the large amounts of RDX and NG/TA and to the large particle size of the RDX. There was also some thought that the poor mechanical properties of the incompletely cured RX-35-AN added to the shock sensitivity of the material.

* Dow Chemical Co.

† Mobay Chemical Co.

‡ Alpha Chemical Co.

Table 1. LOVEX formulations, in weight percent.

Formula	RDX	NaNO ₃	Al	NG/TA	Binder
RX-35-AJ	12.0	56.0	12.0	14.0	6.0
RX-35-AK	20.2	55.0	—	17.9	7.1
RX-35-AN	16.0	41.0	15.0	19.0	9.0

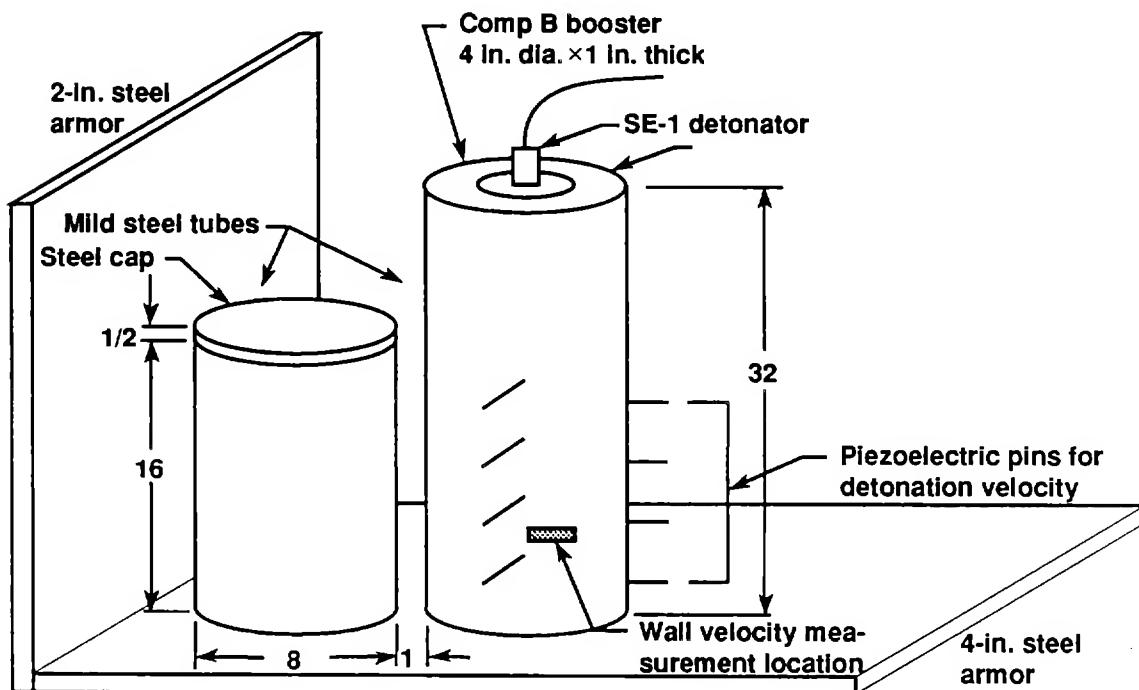


Figure 1. Experimental configuration. Dimensions are in inches.

Experimental

Formulations were processed in the 1-gal Baker-Perkin vertical high-shear mixer (1.5 to 2 kg), and larger-scale mixes in the 100-gal melt-cast kettle (50 kg). The materials used were as follows:

RDX : Hexahydro-1,3,5-trinitro-1,3,5-triazine, type B, class 6 manufactured by the Holston Army Ammunition Plant, USA.

NaNO₃ : Sodium nitrate is acquired from Ashland Chemical as a prill and hammer-milled to 25- to 250-μm particle size.

Aluminum : Spherical, atomized aluminum metal powder produced by Alcoa (Alcoa S-9280, 5- to 15-μm range or Alcoa 8122, 15-μm average particle diameter).

NG/TA : Nitroglycerin/triacetin is a 75/25 by weight mixture made by the Naval Ordnance Station, Indian Head, MD.

Polymer binder: Dow Chemical poly(ethylene glycol) 4500; Union Carbide poly(*e*-caprolactone) Tone 6000 (made on order); Mobay Chemical Desmodur N-100 isocyanate; catalyst is Coscat 83 (a triphenyl bismuth-based proprietary formula) by Boulder Chemical Company.

The viscosities of various formulations were measured at the end-of-mix by using a Brookfield Viscometer Model HBT with T-bar spindles. To determine extent of cure, we measured Shore A hardness on samples by using a Pacific Transducer Corp. Durometer Model 306L.

The materials preparation and processing sequence that gave reproducible cure reactions was as follows. The NaNO₃, RDX, and PEG and Tone polymers were vacuum dried overnight at 50°C. The polymers (a 1:1 ratio on equivalents) were dissolved in the NG/TA overnight at 60°C. The solution was cooled to ambient temperature, and the catalyst (Coscat 83) was stirred into the solution for 10 min. N-100 isocyanate was added into the catalyzed solution at 115% of stoichiometry and stirred for 10 min. Half the aluminum, NaNO₃, and RDX powders were added and stirred for 15 min. to wet the powders. The remaining powders were added and stirred for 10 min., after which the mixture was stirred at medium to high RPM with vacuum for 30 min. The material was ready for use at this point.

Initial addition of the catalyst, followed by addition of the isocyanate, significantly improved the reproducibility of the binder cure. Alteration of this sequence resulted in greatly variable cures.

Sympathetic-detonation tests were performed on a number of LOVEX formulations with the modified binder system and a range of RDX and NG content. The sympathetic-detonation test setup is similar to that shown in Fig. 1 but without the detonation velocity diagnostics and with both 8-in.-diameter donor and acceptor charges at 16-in. of length. Detonation was determined by witness-plate dent.

Results and Discussion

We processed the new formulations with modified binder and a range of RDX and NG content in the 1-gal Baker-Perkin mixer (2 kg) and the 100-gal melt-cast kettle (50 kg). We determined the viscosities, pot-life, and Shore A hardness of cured material for formulations processed in each mixer and compared the results to determine mixer and scaling effects on formulations. Table 2 lists these formulations.

Figure 2 shows viscosity vs time for all three formulations processed in both the 1-gal vertical mixer and the 100-gal kettle. The mix temperature for RX-35-AS was maintained at 22°C. This lower temperature resulted in crystallization of the polymer with a resultant increase in the viscosity. All viscosity values for the 1- and 100-gal mixers for RX-35-AT fall on the same line. The temperature of this mix was maintained at a higher temperature, 30°C, to keep the polymer in solution and thus the viscosity lowered. The viscosity values for the 1- and 100-gal mixers for RX-35-AQ fall on the same line at mix temperatures of ~22°C. RX-35-AQ uses less dilute NG/TA (72/25) than RX-35-AS and RX-35-AT (60/40).

Table 2. New LOVEX formulations, in weight percent.

Formula	RDX	NaNO ₃	Al	NG/TA	Binder
RX-35-AQ	16.0	41.0	15.0	19.0 ^a	9.0
RX-35-AS	—	51.0	15.0	23.5 ^b	10.5
RX-35-AT	10.0	41.0	15.0	23.5 ^b	10.5

^a NG/TA is 75/25 ratio.

^b NG/TA is 60/40 ratio.

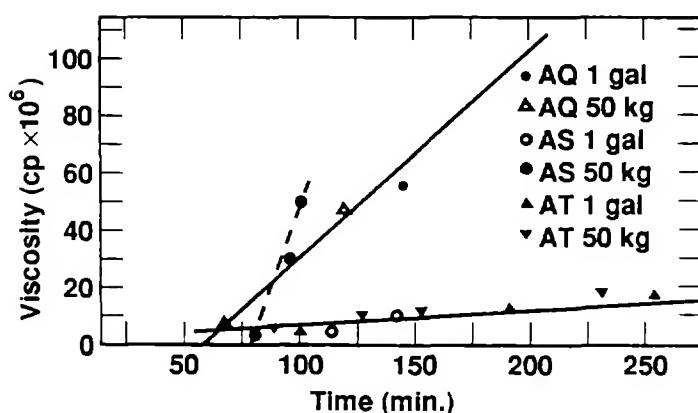


Figure 2. Temporal plot of viscosity of LOVEX formulations after addition of isocyanate.

The NG (nitrate ester) solubilizes the polymer and keeps it in solution, whereas further dilution of NG tends to cause the polymer to crystallize out (at temperatures lower than 30°C). We are currently determining the critical NG/TA dilution ratio that would solubilize the polymer completely. Even at the higher viscosities shown in the plots for RX-35-AS and RX-35-AQ, the materials were easily poured out. When the temperature of the mix for RX-35-AS was raised to 30°C, the polymer went into solution with a subsequent decrease in viscosity. Even at 30°C for RX-35-AS and RX-35-AT, the pot-life was 3-1/2 hr.

Formulations were allowed to gel at room temperature (20–25°C) overnight. After seven days at room temperature, there was little change in the Shore A hardness of the three formulations. Table 3 shows the hardness values after seven days for RX-35-AQ, RX-35-AS, and RX-35-AT. The range within each formulation is typical for the Shore A hardness measurement apparatus. The higher values for RX-35-AS and RX-35-AT were higher than for RX-35-AQ. The difference in hardness is a result of the crystallization of the polymer in RX-35-AS and RX-35-AT.

Sympathetic-detonation tests were performed on RX-35-AQ, RX-35-AS, and RX-35-AT in 8-in.-diameter hardware, and the results are shown in Table 4. All the donors detonated, as determined by witness plate dent. The “go” result for RX-35-AQ acceptor was not unexpected because RX-35-AQ is similar in energetic composition to RX-35-AN, which was a “go” in previous experiments. The theory was not proven that an incomplete binder cure, with a resultant degradation in formulation mechanical properties, had contributed to the shock sensitivity of RX-35-AN in sympathetic detonation. The particle size of RDX, and the amount of RDX and NG seem to be more dominant factors than the overall modulus of the cured formulation.

Future formulations will use small-particle RDX so that its content can be increased in the formulation to further increase the performance while maintaining low-vulnerability characteristics.

Table 3. Shore A hardness of cured LOVEX formulations.

Formula	Shore A hardness
RX-35-AQ	45–55
RX-35-AS	55–60
RX-35-AT	50–55

Table 4. 8-in.-diameter hardware sympathetic-detonation results.

Formula	Result
RX-35-AQ	Go
RX-35-AS	No go
RX-35-AT	No go

Conclusions

We have successfully developed formulation compositions that do not sympathetically detonate in 8-in.-diameter hardware and that also have very attractive processing properties such as low viscosity, long pot-life, and room-temperature cure.

We are continuing to optimize the binder chemistry, use decreased particle size RDX, and use energetic liquid plasticizers other than NG/TA in LOVEX formulations to determine resultant thermal stability effects.

Reference

1. C. Prunedo, E. Jessop, R. McGuire, *Low-Vulnerability Explosives (LOVEX) for Mass-Use Warheads*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-102391 (1990).